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CLUB-ROOT IN THE UNITED STATES.

By A. C. EYCLESHYMER.

(Plates XV, XVI.)

Since the disease club-root is forcing itself more and more upon the attention of American agriculturists, it is of the utmost importance that all the facts, at present known, concerning this destructive disease should be brought together, that the best means for its prevention may be suggested. With this end in view, a series of inquiries was addressed by the writer in 1889, to practical gardeners throughout the United States, and also to the officers of experiment stations and others likely to be able to give information regarding distribution, cause, remedies, etc. At the same time experiments were carried on in the hothouse, seedlings of cabbages and turnips being raised under conditions favorable for the development of the parasite and infected by mixing portions of diseased turnips with the soil. The correspondence and experiments were continued during two seasons. The results are communicated in the following preliminary report, as the work for the present has been interrupted, so that the series of experiments undertaken can not be completed.

The origin of the disease is not known. Its existence in Scotland was first detected in 1780, but little damage was caused until 1820. This is the earliest knowledge we have of the disease. It is at present known in England, Scotland, and Ireland, as ambury, anbury, hanbury, and fingers-and-toes. In Russia, kapoustnaja kila. Germany, kohlhernie. Belgium, vingerziekt. France, maladie digitoire. In the United States it is known by the various names, club-foot, club-root, clump-foot, and clubbing.

Its distribution in the United States is quite difficult to ascertain. There is no doubt, however, that its stronghold at present is in the New England and Middle States, especially in Connecticut, Rhode Island, Massachusetts, New Jersey, Delaware, and in the southeastern portions of New York and Pennsylvania. From this region it has extended southward through Maryland and Virginia to the Carolinas. The disease has occurred in Missouri, Illinois, Wisconsin, Iowa, and Michigan. Beyond the regions just named there is not sufficient evidence of its appearance.

The amount of damage caused by the disease is enormous. Woronin estimates the loss in the vicinity of St. Petersburg, Russia, for the year 1876, at $225,000. In the United States, wherever the disease is prevalent, it is considered one of the worst enemies of the market gardener, destroying in many cases the entire crop.

The plants affected are for the greater part confined to the genus *Brassica*, including the cabbage, cauliflower, turnip, and rutabaga. Halsted has recently described it as occurring on the radish. In Russia it also affects the genera *Matthiola* and *Iberis*.

The disease attacks the young seedlings and generally shows itself in from three to five weeks. It is first indicated externally by the so-called "flagging" of the leaves. The chlorophyll no longer shows the dark green color characteristic of perfectly healthy plants, but a lighter and yellowish tinge. Upon examining the roots of the plants thus affected there are found tubercular outgrowths or excrescences varying in size, according to age, from those scarcely distinguishable to those ten or twelve times the diameter of the normal root. These swellings seem to be confined exclusively to roots, never occurring on the stem or leaves.

Under the various names by which the disease is known probably many tubercular swellings have been described which bear no relation to true club-root. Buckman[7],[*] for example, says: "Every field, whether of parsnips, carrots, or turnips, will contain roots affected with finger-and-toe," and claims this to be a reversion to their original wild form, but he has evidently given a description of the digitate appearance as distinguished from the smooth unbranched condition of well-developed specimens.

So closely do the characteristics resemble those present on the roots of the potato, tomato, and parsnip caused by a nematode that one would consider them, from a mere casual examination, to be identical. In speaking of these galls Atkinson[3] says: "In external appearance the enlargements of the roots of the Cruciferæ, which are called club-foot, very much resemble the root galls. Unless one was pretty certain of the locality from which the diseased specimens came, it would be venturesome to undertake to say whether it was root gall or club-foot."

Another form of tubercular swelling is that found on various specimens of Leguminosæ (clover, beans, peas, vetches, etc.) described by Ward[32], Brunchorst[6], Schindler[28], Tschirch[3], Prazmowski[23], Beijerinck[4], and others. Since there is considerable variation on the roots of different species, there might arise some difficulty in distinguishing these from club-root. Seignette has recently described swellings probably due to variation of temperature. The fact that various forms of excrescences on roots are plainly due to widely different causes indicates the necessity of discrimination in order to avoid confusion.

Careful examination of the outgrowths occurring on the roots and rootlets of the genus *Brassica* show the elongated, fusiform swelling to be more characteristic of those occurring on the cabbage (Plate XV, Fig. 1), while those on the turnip are round or oval (Plate XV, Fig. 2). Extended comparison of diseased turnips and cabbages give no support to the view of W. G. Smith that the cause of the disease can be predicted from the form of the swellings. To the unaided eye these outgrowths, especially in the earlier stages, do not seem to differ either internally or externally from the sound tissue. In the later stages there is a change from pearly white to a yellowish brown. Instead of a smooth convex outline the surface is full of fissures, secondary fungi gain access, decomposition begins, and the foul odor arises which is so characteristic of the disease. These appearances are especially noticeable in the turnip. (Plate XV, Fig. 3.)

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[*] The numbers given after authorities refer to the bibliography at the end of the paper.

In the study of the minute anatomy use was made of freehand sections. Serial sections were also used to a considerable extent, the material being embedded in celloidin and cut with the microtome. Sections through stem and leaf show no trace of any parasite. If a transverse section of one of the spindle-like swellings of the cabbage be cut along the line *a*, *b* (Plate XV, Fig. 4), where the hypertrophy is least marked, and examined with a low power, a more or less mottled appearance is seen (Plate XV, Fig. 5). This is due to the presence of the parasite *Plasmodiophora brassicæ*, Wor.[37], which is undoubtedly the principal cause of the club-root disease. A very noticeable feature is that, in general, this appearance is found in the vicinity of the cambium *c* and tracheæ *tr* of the axial portion. Examination with a higher power shows this mottled appearance to be due to the presence of minute spherical bodies, which are so densely packed that the entire lumen of the cell is filled. Sections of the turnip along the line *a b* (Plate XV, Fig. 6) show different stages in the development of the Myxomycete. There is often found in the same section all the transitional stages between the plasmodium and mature spores (Plate XV, Fig. 6ª *a*, *b*, *c*). The individual cells of the thin-walled parenchyma undergo a marked hypertrophy. This is shown by comparing Figs. 7 and 8. The drawings are made from the same section taken along the line *c d* of Fig. 6, Plate XV. Fig. 7 shows the normal tissue of the cambium zone taken from the right side, while Fig. 8 shows the pathological condition as it occurs on the opposite side. If the peripheral layers *a* be made to coincide, a comparison is readily made. Moreover, this swelling is noticed in cells surrounding those infected and where no trace of the parasite could be found. Yet this is not sufficient to account for the enormous tubercles shown in Plate XV, Figs. 1 and 2. This would seem to justify Woronin's[37] statement that the swellings are not only caused through the hypertrophy of individual cells, but also by an increase through cell division. The tracheæ apparently undergo no changes. Plate XVI, Fig. 9, taken from a section along the line *a b* of Fig. 10 shows one of the vessels more highly magnified. It is completely filled with the plasmodium, while the surrounding tissue is free from any trace of disease. This at once suggests that the parasite may thus be readily carried to different parts of the tissue. If now the contents of the cells of the medullary rays be examined they are found, in the normal tissue, to be loaded with starch. Comparing the pathological tissue from the same region a marked change is noticed. Instead of the small cells well stored with reserve food, we have the

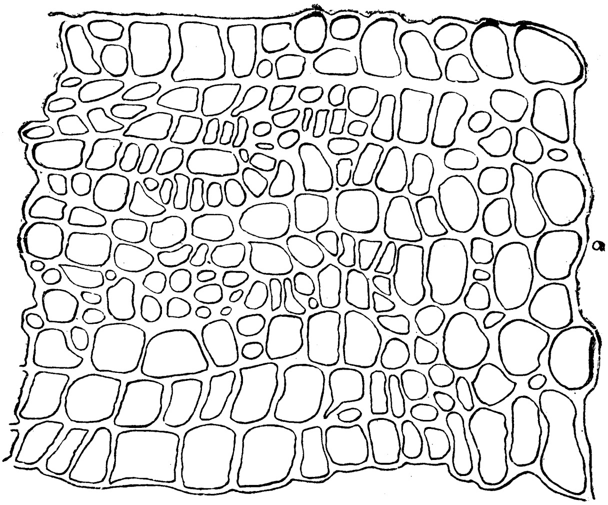

FIG. 7.—Transverse section along line *cd* of Plate XV, Fig. 6. The portion represented is taken from the normal tissue found on the right side, × 200.

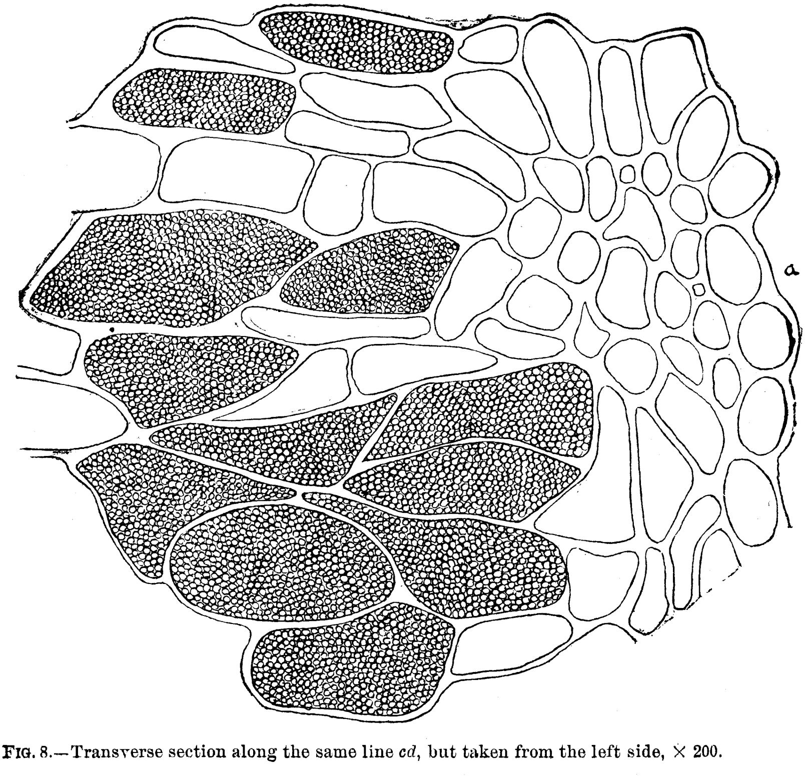

FIG. 8.—Transverse section along the same line *cd*, but taken from the left side, × 200.

enormously swollen cells shown in Plate XV, Fig. 6^a, in which there is no trace of the starch, *i. e.*, so far as could be determined by the use of iodine. Testing with Schulze's solution, or hydrochloric acid and phloroglucine, a lignified condition of the cell walls is found, though to a less degree than in the regions where the cells are entirely filled with spores. Often the cells of the cambium are so pressed out of shape that the tangential walls alone are distinguishable.

If a bit of the tissue, in which spores are found so abundantly, be placed under a cover glass and lightly tapped the spores are set free. If the slide be now placed in a moist chamber and allowed to remain from four or five to twenty-four hours, the swarm cells are distinguished either on the slide (Plate XVI, Fig. 11), or escaping from the spores (Fig. 12). The appearance of the swarm cell after escaping is that of an irregular protoplasmic mass which undergoes greater or less changes in contour. Plate XVI, Fig. 11 *a*, *b*, *c*, *d*, *e*, *f*, *g*, represent the changes of outline through which one of the swarm cells passed in about fifteen minutes. A very much elongated process, cilium, is often observed (Fig. 11*a*). The nucleus is often plainly visible (Fig. 11*e*, *f*). Nothing could be determined as to nuclear changes. It seems fair to suppose, however, that these correspond to what has been observed in other Myxomycetes. It is in this stage of its existence that the organism is supposed to penetrate the root hairs, and thus gain access to the deeper parts of the cortex. Repeated endeavors were made by means of slide cultures to observe the penetration of these swarm cells, but without success. This is a point that needs further observation. The penetration has never been observed, and it is possible that it is through ruptures in the tissue, caused by insects, worms, or other forms, which are constantly present in the soil. If the slide be kept in a moist chamber for four or five days, other and larger forms are present (Plate XVI, Fig. 13), while the swarm cells have almost entirely disappeared. It is quite probable that the larger forms result from a fusion of the swarm cells, but direct proof is wanting. These forms undergo the same changes of outline as described for the swarm cell (Plate XVI, Fig. 13*a*, *b*, *c*, *d*). A nucleus is plainly visible and a pulsating vacuole is present. It is worthy of note that in the tissues these forms are never observed, while in slide cultures they are very abundant. Another condition observed is represented in Plate XVI, Fig. 14, and may be designated as an early plasmodial stage. In most cases it does not at first fill the entire lumen, and more or less branching filaments extend to the walls of the cell, often apparently continuous with the plasmodium of the adjoining cell. It often presents a somewhat aggregated appearance (Plate XVI, Fig. 14). Vacuoles are always present. They are, however, of a decidedly different nature from those found in the forms represented in Plate XVI, Fig. 13. In that, no pulsation is observed. Nuclei can not be observed by the use of ordinary nuclear stains; acetic methyl green; picric aniline blue; acetic carmine, etc. The absence of starch in all cells occupied by plasmodia leads one to strongly suspect it has been digested by the mass. Dr. Wortman performed experiments which seem to show conclusively that the plasmodium of Fuligo took in and digested starch grains. It is highly probable that the same takes place in the plasmodium above described. In this would be found an explanation of the fact already referred to, that in the medullary rays of diseased parts no trace of the starch can be found.

Passing to stages which are probably later, since they occur in tissue where ripe spores are very abundant, the plasmodium is found filling the entire lumen of the cell and presenting a reticulated granular appearance (Plate XV, Fig. 6^a *a*). Another appearance often noticed is represented in Fig. 6^a *b*, where the granules have an aggregated aspect. These are probably changes immediately preceding spore formation, Fig. 6^a *c*. A very peculiar appearance of the plasmodium is shown in Plate XVI, Fig. 15. The significance of this is unknown. A possible explanation might be the irritation caused by the presence of bacteria, but a series of transitional stages between those indicated in Plate XVI, Figs. 15 and 16, were observed.

The ripe spore is composed of a thin, transparent, refractive outer portion inclosing a more or less granular matrix, in which are embedded bodies of varying size, form, and refractive power (Plate XVI, Fig. 12). The nature of the bodies could not be determined; they may be nuclei or oil globules. From each of these spores a swarm cell escapes into the soil, where it may come in contact with the rootlets of the young plant.

Among cabbages, and in fact all members of the genus *Brassica*, there seems to be no variety exempt from attack. Many varieties were sown in the same soil under similar conditions, and so far as could be determined no differences were present. From correspondence the same conclusion is reached. It is claimed that the rutabaga is less liable to attack than the common variety, and when sown in alternate drills with "purple top" they produce a fair crop, while the latter is much affected. As to the variety of radishes attacked, no information is at hand. It is now generally conceded that the disease occurs after all kinds of crops. The market gardeners consider it dangerous to grow cabbage or turnip crops on the same ground for even two successive years. Rotation is absolutely necessary. After a cabbage or turnip crop all débris should be carefully removed and burned.

It has been claimed that early sowing was the cause of the disease. While this is untenable, there is undoubtedly a great tendency for early sown crops to become infected, especially if the season be a wet one, thus making the conditions for the germination of the spores more favorable. The disease is said to be more prevalent along trodden paths indicating that the rolling of ground is unadvisable.

There can be no doubt that the disease is propagated to a considerable extent through the decayed material left on the field. Yet one is puzzled to account for the well established fact that it is found occasionally on newly broken ground where no crop has ever yet been grown. This would seem to indicate that certain soils harbor the organism as a saprophyte. Poorly drained ground often shows the same tendency. The soils otherwise best adapted for cabbage growing are those on which the organism can survive best, *e. g.*, bogs and swamps which are rendered arable, but crops grown on sandy loam are less subject to the disease, as are also those grown on calcareous soils. Wherever a limestone formation outcrops both cabbages and turnips are comparatively free from attack. Some of the Long Island gardeners raise cabbages season after season on the old shell heaps without any trace of the disease.

It often occurs that turnips or cabbages grown on ground previously covered with compost heaps show the disease, while the plants all around them are free. Fertilizers should not be spread over the ground in the autumn, since it is known that the various kinds of manure form an excellent substratum for the development of certain Myxomycetes. If applied, it should by all means be thoroughly fermented.

It is quite evident, from the nature of the disease, that after having gained access there is probably no cure. Preventives are apparently the only means by which the ravages of the disease may be averted. Probably the want of clean cultivation is one of the most fruitful sources by which the disease is propagated. Of all the various preventives, ashes, salt, chalk, lime, bisulphide of carbon, etc., suggested by both gardeners and scientists, lime seems to be the most effectual. If applied to the land during the spring immediately preceding, it very seldom has any effect on the ensuing crop, but if applied a year and a half before, it almost invariably has a surprising effect in preventing the disease. It is only by extended experiments that the best methods of application can be determined. Since many believe the disease originates largely in the hot-bed before transplanting, sterilization of the soil should be tried. Mixing certain proportions of unslaked lime with the soil used in the hotbed will undoubtedly modify, to a considerable extent, the occurrence of the disease. Hulst[16] makes a saturated aqueous solution of chloride of lime, sold by druggists as "bleaching powder." This solution is diluted with three parts water and applied to the roots of the plants and to the surrounding soil at the time of transplanting. In from two to three weeks this is followed by a second application.

In conclusion, I wish to call attention to certain forms that are almost constantly present. Sections of tissue containing plasmodia are rarely examined in which there are not present minute bodies undergoing vibratory movements very similar to that known as the "Brownian movement." The granules are very large, and indeed so much do they resemble micrococci that one is led almost irresistibly to the conclusion that this is the explanation. If this be true it is questionable to just what extent we are dealing with true plasmodia. Ward[32] finds the so-called plasmodia described by various authors as occurring in the tubercles found on the roots of *Vicia Faba* to be nothing more than the protoplasm of the cells, stimulated into increased activity by parasitic gemmules. While there is but little doubt that *Plasmodiophora brassicæ*, Wor., is the principal cause of club-root, it is by no means improbable that bacterial forms play quite an important part. Pure cultures should be made of the various forms so generally present and inoculation experiments tried.

I hereby desire to acknowledge with sincere thanks the assistance I have received through the kindness of Prof. Spaulding, under whom the work was begun and has been carried thus far. I am indebted to Dr. Erwin F. Smith of the Division of Vegetable Pathology of the U. S. Department of Agriculture, to Dr. Byron D. Halsted of the New Jersey Experiment Station, and to Mr. George A. Schultz, of Jamesburg, N. J., who kindly furnished me with material. To the botanists of the various experiment stations and other correspondents, whose suggestions have been of much value, I am also under obligations.

UNIVERSITY OF MICHIGAN, *February 14, 1891.*
BOTANICAL LABORATORY.

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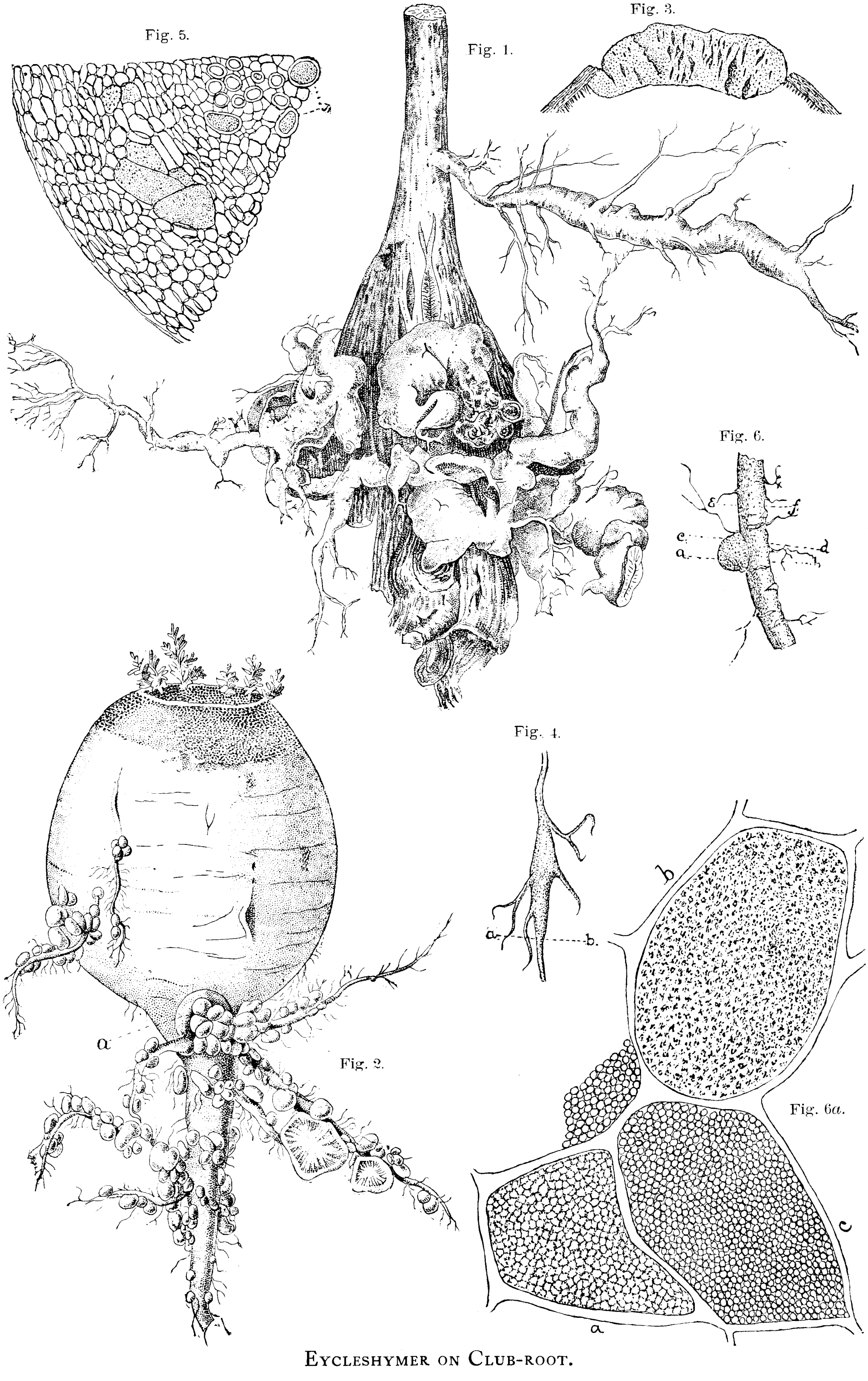

EYCLESHYMER ON CLUB-ROOT.

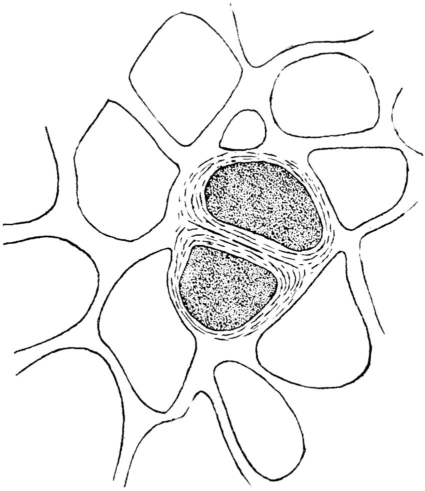
Fig. 9.

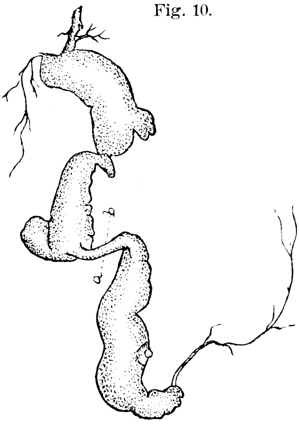
Fig. 10.

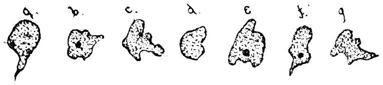
Fig. 11.

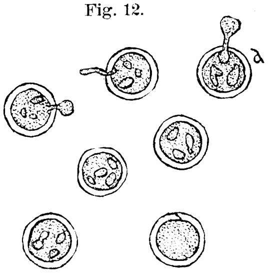
Fig. 12.

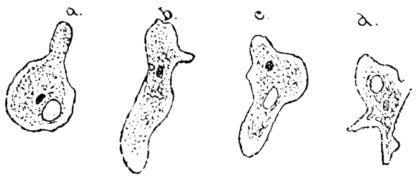
Fig. 13.

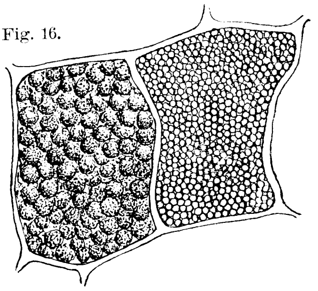
Fig. 16.

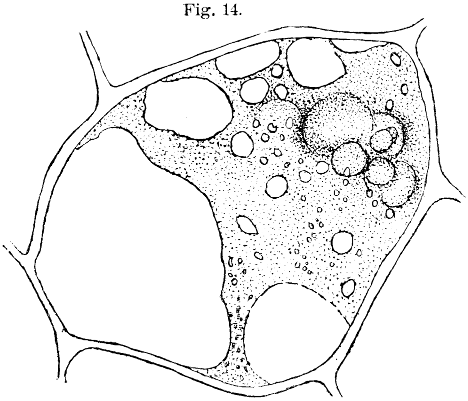
Fig. 14.

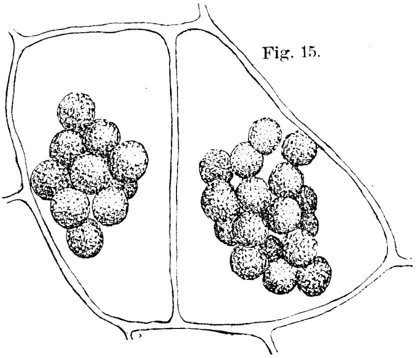
Fig. 15.

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EXPLANATION OF PLATES.

Plate XV.

Fig. 1. Specimen of diseased cabbage, after Woronin. Natural size.
2. Specimen of diseased turnip root, after Sorauer. Natural size.
3. Portion of transverse section of turnip. Natural size.
4. Rootlet of cabbage showing condition seven weeks after infection. Natural size.
5. Transverse section of rootlet along the line *ab* in which the spores are present, × 65.
6. Portion of root of turnip seven weeks after infection. Natural size.
6*a*. Cells from tranverse section along line *ab* Fig. 6, × 200.

Plate XVI.

Fig. 9. Vessel from axial portion. Section taken from along line *ab*, Fig. 10, × 600.
10. Diseased rootlet of cabbage. Natural size.
11. Swarm cell drawn at short intervals to show constant change in outlines, × 1,200.
12. Ripe spores from some of which swarm cells are apparently escaping, × 1,200.
13. Probably early stages of plasmodia, × 600.

Fig. 14. Normal plasmodium as found in early stages of the disease, × 600.
15. Aggregated appearance of plasmodium × 300.
16. Section showing another aggregated appearance in which the spherical masses are much smaller, × 200.

FIELD NOTES, 1891.

By Erwin F. Smith.

It can scarcely be doubted that climatic conditions exert a marked influence on the spread of many fungous diseases. Bad weather may render the host more susceptible, or only afford the parasite increased facilities for multiplication, or both. Under just what set of conditions in particular cases the fungus is most likely to attack the host, or is certain to do so, are points on which, for the most part, there is not yet enough evidence to decide positively, but as time goes on we may confidently expect to see many of these problems worked out fully, our knowledge of the complex relations of host and parasite being yet only in its infancy.

In this series of notes my desire is simply to put on record certain observations which may contribute toward the solution of a most interesting problem of phytopathology. There is no doubt that mycologists must become closer observers of local weather conditions and of the individual, varietal, and specific peculiarities of plants, if they would satisfactorily explain the behavior of many fungous diseases.

PEACH CURL.*

It is well known that gardeners and fruit-growers have frequently ascribed this disease (mildews, also) to the depressing influence of cold. Mycologists, on the other hand, since the discovery of Taphrina, have, perhaps too generally, assumed the direct cause to be the only necessary factor in the production of curl.

The conditions under which peach curl appeared in the orchard of Mrs. W. O. Shallcross, at Locust Grove, Md., in the spring of 1891, are so peculiar and bear so directly on the point at issue that it seems worth while to set them down somewhat fully. This orchard contains about 1,050 trees, now set five years. It is situated on the east side of Chesapeake Bay, on loose, thin upland, in a region of extensive orchards, the nearest being about one-half mile distant. Peach curl due to Taphrina is not troublesome in eastern Maryland or Delaware. It was present in quantity for the first time in many orchards in Kent County, in 1890, and was so much more than usually abundant everywhere as to receive notice in this Journal (Vol. vi, p. 107). Probably there was more or less of it in this orchard, but not enough to attract special attention.

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* *Taphrina deformans* (Berk.), Tul.